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Short communication

The effect of fruit orientation of postharvest commodities following low dose ultraviolet light-C treatment on host induced resistance to decay

C. Stevens[a,*], V.A. Khan[a], C.L. Wilson[b], J.Y. Lu[a], E. Chalutz[c], S. Droby[c]

[a]George Washington Carver Agricultural Experiment Station, Room 207 Milbank, Tuskegee University, Tuskegee Inst., AL 36088, USA
[b]USDA, ARS, NAA Appalachian Fruit and Research Station, Kearneysville, WV 25430, USA
[c]ARO, The Volcani Center, Bet Dagan 50250, Israel

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Abstract

The possibility of inducing resistance to bitter rot (*Colletotrichum gloeosporioides*), brown rot (*Monilinia fructicola*), and green mold (*Penicillium digitatum*) in apples, peaches, and tangerines, respectively, by treating them with ultraviolet light-C (UV-C light) at the stem end in a stationary position without rotation was investigated. This approach was compared with the conventional procedure where fruits were rotated four times, thereby exposing the entire surface area to the full effects of the UV-C light. Results revealed that when the stem ends of apples, peaches, and tangerines were exposed in a stationary position to dosages of 7.5, 7.5 and 1.3 kJ m^{-2} of UV-C light, respectively, induced host resistance to postharvest decay which was equal to, or slightly better than when fruits were rotated four different times. When fruits were rotated, exposing only one or two different sides to UV-C light, the percent infection appeared to increase, compared to treating only the stem ends or when fruits were rotated four times.

Keywords: Hormesis; Ultraviolet light-C; Postharvest decay; Induced resistance

1. Introduction

A relatively new crop protection technology that involved exposing fruits and vegetables to low dose hormetic (adj. of hormetin, the agent of hormesis) ultraviolet light (UV-C, 254 nm) has been reported in two reviews, to produce biopositive effects such as induce resistance to postharvest decay (Stevens et al., 1996b; Wilson et al., 1994). This phenomenon is termed radiation hormesis (Luckey, 1980). This contrasts to the germicidal effect of similar UV-C dosage, which showed an inverse relationship between UV-C doses and the amount of propagule of the fungus and number of infected wound lesions found on the surface of a fruits (Stevens et al., 1998).

The development of a hormetic low-dose UV-C on-line apparatus to treat harvested fruits, is being considered as a commercial alternative to chemical fungicide applications to treat fruits to control post-harvest decay (Wilson et al., 1997). However, further studies of UV-C application to harvested commodities need to be conducted before a commercial on-line operation can become a reality. At this time the effectiveness and reliability of UV-C treatment needs improvement (Wilson et al., 1997). All postharvested commodities studies in the past have used low hormetic doses of UV-C to induce host postharvest decay resistance, by manually exposing the entire fruit surface to UV-C light by rotating the treated commodities four times (Stevens et al., 1996a, 1998). This manual rotation

*Corresponding author.
E-mail address: cstevens@tuskegee.edu (C. Stevens).

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system to ensure proper low-dose UV-C coverage to harvested fruits is not practical for an on-line apparatus.

The objective of this study was to determine the effects of only exposing the stem end, and one side (used as a UV-C control) of the fruit in a stationary position without rotation to low-dose UV-C light, to evaluate the effects on induced resistance to bitter rot of apples (caused by *Colletotrichum gloeosporioides* [Penz.] Sacc.), brown rot of peaches (caused by *Monilinia fructicola* [Wint.]) and green mold of tangerines (caused by *Penicillium digitatum* [Sacc.]). These different fruit orientation positions were compared with the conventional four time rotation procedure normally used to treat postharvest commodities (Stevens et al., 1996a, 1998).

2. Materials and methods

2.1. Fruits used

"Elberta" peaches [*Prunus persica* (L.) Batsch var. *Persica*] were harvested from E.V. Smith Research Center, Alabama Agriculture Experiment Station Auburn University, Shorter, Alabama. "Golden Delicious" apples (*Malus domestica* Bork.) were shipped from the Appalachian USDA/ARS Fruit Research Station, Kearneysville, West Virginia. "Dancy" tangerines were (*Citrus reticulata Blanco*) obtained from Whitmore Citrus Foundation Farm, USDA/ARS, Clearmont, Florida.

2.2. UV-C irradiation method

The UV-C application procedure of using a low-pressure mercury-vapor discharge lamp (General Electric, Fairfield, CT) emitting quasi-monochromatic UV radiation at 254 nm was used. The UV-C dose rate was measured by a UVX radiometer (UVP, Inc., San Gabriel, CA) with UV-C dose rate of $1.26\,mW\,cm^{-2}$. Apples, peaches, and tangerines, were placed on a tray approximately 10 cm from the surface of the lamp, and exposed to UV-C. UV-C doses of 7.5, 7.5 and $1.3\,kJ\,m^{-2}$ were applied to apples, peaches, and tangerines, respectively, in four different comparative methods:

(a) *Conventional four sided rotations*: Under this method each UV-C dose was subdivided into four subdoses and each side of the fruits was manually rotated to expose the stem and blossom ends, and both sides according to the procedures previously described by Stevens and colleagues (Stevens et al., 1996a, 1998 and Wilson et al., 1994, 1997).

(b) *Two-sided rotation*: Under this method the UV-doses were partitioned into two subdoses and two sides of each fruit were exposed to the UV-C.

(c) *Stem-end stationary treatment*: Under this method the UV-C dose was not subdivided and was only applied to the stem end of each fruit without rotation.

(d) *One-side stationary application*: One side of each fruit was placed in a stationary position and the full dose of UV-C was applied without any subdivision of the dose and no rotation of fruits. All fruits were arranged in a completely randomized design, and the UV-C doses were applied to three replicates of 10–20 fruits for a total of 30–60 fruits per UV-C dose. Each experiment was repeated twice.

2.3. Fungal inoculum preparation and artificial inoculation

After 72 h following UV-C application, treated and non-treated (control) fruits were surface sterilized with 95% ethanol, and wounded with a sterile dissecting needle to a depth of 3 mm. Apples and peaches were inoculated near the stem end, middle and blossom end, while tangerines were inoculated at the blossom and stem ends only. *C. gloeosporioides*, *M. fructicola*, and *P. digitatum* were isolated and maintained in vitro on potato dextrose agar (PDA) in Petri dishes at 28 °C for 7–14 days. All pathogen isolates were isolated from decayed fruits. Twenty micro liters of conidial suspension (10^5 conidia ml^{-1}) of each pathogen was applied to each wound of every fruit as described previously (Stevens et al., 1996a). UV-C treated and non-treated control inoculated fruits were incubated in non-sealed plastic bags with moist filter paper for 2 days at room temperature (24–26 °C). Following inoculation with conidial suspensions of each fungus, evidence of decay around wounds usually occurred within 24 h. The percent infection was determined by assessing the number of wounds that developed lesions, out of the total number of wounds inoculated. When all fruits showed evidence of complete decay after two days from the establishment of infection they were removed from plastic bags and placed in open trays where lesion diameters were determined as described previously (Stevens et al., 1996a, 1998). Treated tangerine fruits were stored for an additional 7 days and apples and peaches were stored for 8 days at 24–26 °C in open trays.

2.4. Statistical analysis

All data were statistically analyzed using SAS analysis of variance (ANOVA) package. Treatment means were compared by orthogonal comparisons (SAS Institute, 1995).

3. Results and discussion

Results revealed that when just the stem ends of apples, peaches, and tangerines were treated with UV-C light in a stationary position, they resisted postharvest decay. The results obtained were equal to or slightly better than when the fruits were rotated four times (Tables 1–3) as required in the conventional orientation method (Stevens et al., 1996a, b, 1998). However, when the fruits were not rotated and only one side was exposed or when the fruits were rotated two different times exposing two sides of each fruit to the UV-C, susceptibility to decay appeared to increase (Tables 1–3).

This difference in response could be attributed to the fact that the application of low-dose UV-C penetrated the outer layers of the skin at the stem end of each fruit, or all sides of the fruit (Luckey, 1980; Day et al., 1993; Tevini et al., 1991), where the light contacted the site of UV-C photoreception. (Ensminger, 1993; Mulligan et al., 1997). A possible signal by way of the transduction pathway from the receptor tissue could have been transmitted systemically from the stem end of the fruits to numerous strands within the phloem vascular tissue of fruits (Artschwager, 1924). It is also possible that the translocation was rapid, because there was a significant increase in the level of defensive responses to retard *M. fructicola*, *C. gloeosporioides*, and *P. digitatum* invasion in peaches, apples, and tangerines, at the blossom end (Tables 1–3). Further, the results of this study seems to show a lesser defensive response in fruits treated at one side of the nonrotated and those rotated two times in retarding these pathogens, compared to those treated at the stem end only. This could possibly mean a slower translocation of a vascular mobile transduction signal.

The stationary stem-end positioning of fruits for postharvest UV-C treatment would be more efficient for an on-line UV-C apparatus and less laborious than the conventional four-side rotation, which would involve

Table 1
Effect of fruit orientation of apples during UV-C light treatment and after artificial inoculation with *Collectotrichum gloesporioides* (causing bitter rot)

		Percent infection (and lesion diameter (cm)) Inoculation sites			
Fruit	Fruit orientation	Stem	Middle	Blossom end	Avg.
Apple	UV-C stem end (non-rotated)	16 (4.4)	16 (4.6)	12 (3.7)	15 (4.2)
	UV-C (1 side non-rotated)	56 (6.2)	65 (6.6)	47 (5.7)	56 (6.2)
	UV-C (4-side rotation)	18 (4.3)	30 (4.7)	18 (3.8)	22 (4.3)
	UV-C (2-side rotation)	38 (4.8)	58 (5.0)	53 (4.0)	50 (4.6)
	Control (untreated)	97 (7.1)	94 (7.8)	93 (6.4)	95 (7.1)
Significance of F-test from ANOVA					
Control vs. treated				$P<0.01$	
Conventional vs. stem end				$P<0.01$	
2-side rotation vs. stem end and 1 side				$P<0.05$	
Stem end vs. 1 side				$P<0.05$	

Table 2
Effect of fruit orientation of peaches during UV-C light treatment and after artificial inoculation with *Monilinia fructicola* (causing brown rot)

		Percent infection (and lesion diameter (cm)) Inoculation sites			
Fruit	Fruit orientation	Stem	Middle	Blossom end	Avg.
Peach	UV-C stem end (non-rotated)	20 (7.2)	20 (8.3)	20 (7.3)	20 (7.6)
	UV-C (1 side non-rotated)	20 (7.7)	80 (10.0)	50 (10)	50 (9.2)
	UV-C (4-side rotation)	20 (7.0)	40 (8.2)	20 (8.0)	20 (7.7)
	UV-C (2-side rotation)	—	—	—	—
	Control (untreated)	100 (18.0)	100 (17.4)	100 (17.4)	100 (17.5)
Significance of F-test from ANOVA					
Control vs. treated				$P<0.01$	
Conventional vs. stem end				$P<0.05$	
2-side rotation vs. stem end and 1 side				NS	
Stem end vs. 1 side				$P<0.05$	

Table 3
Effect of fruit orientation of tangerine during UV-C light treatment and after artificial inoculation with *Penicillum digitatum* (causing green mold)

Fruit	Fruit orientation	Percent infection (and lesion diameter (cm)) Inoculation sites			
		Stem	Middle	Blossom end	Avg.
Tangerine	UV-C stem end (non-rotated)	20 (0.9)	—	20 (0.7)	20 (0.8)
	UV-C (1 side non-rotated)	—	—	—	—
	UV-C (4-side rotation)	26 (0.9)	—	29 (0.7)	28 (0.8)
	UV-C (2-side rotation)	63 (1.2)	—	63 (1.0)	63 (1.1)
	Control (untreated)	93 (1.5)	—	93 (1.2)	93 (1.4)
Significance of F-test from ANOVA					
Control vs. treated				$P<0.01$	
Conventional vs. stem end				$P<0.05$	
2-side rotation vs. stem end & 1 side				$P<0.05$	
Stem end vs. 1 side				NS	

periodic manual rotation of fruits on the processing line (Wilson et al., 1997). Also, there are other practical advantages for treating at the stem end only with UV-C, such as treating smaller fruits such as strawberries, kumquats, grapes, and large irregular-shaped vegetables such as sweet potatoes and cone-shaped carrots.

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